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Respirable Dust Exposure and Respiratory Health in Male Taiwanese Steelworkers

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Abstract: The objective of this cross-sectional study was to investigate the prevalence and determinants of respiratory symptoms and lung function and their association with occupational dust exposure in Taiwanese steelworkers. The study was conducted on an integrated-steel company in Taiwan from March 1989 to February 1990. After excluding workers in the coke ovens and ex-smokers, we performed physical examinations on 1,339 male workers in the iron making and steel making factories. Subjects were interviewed regarding respiratory symptoms using a Chinese version of the American Thoracic Society respiratory questionnaire and were examined with respect to their lung function using spirometry. Objective dust exposure was measured using personal air sampling with 277 valid samples. Prevalences of cough frequently, chronic cough, phlegm frequently, chronic phlegm, wheezing occasionally, and breathlessness were 11.4%, 9.3%, 14.6%, 11.9%, 2.6%, and 6.5%, respectively. Duration of employment, smoking, subjective dustiness, and past respiratory illnesses can predict these respiratory symptoms. Average respirable dust exposure significantly decreased the forced vital capacity (FVC) and forced expiratory volume in one second ($FEV_{1.0}$) in smoking workers. In the non-smokers, an effect of respirable dust exposure on $FEV_{1.0}$/FVC was shown. Since the main ingredients of dust in such a steelworks usually contained mixtures of oxides and silicates other than silica dust, respirable dust exposure in steelworks might impair lung function, especially among smokers.

Key words: Cross-sectional studies, Respirable dust, Occupational exposure, Questionnaire, Respiratory function tests

Introduction

An integrated steel plant uses many different raw materials and produces many intermediates, by-products and products. Among these, there are many substances potentially harmful to the health of steelworkers. Hazardous dust is one of the most important exposures in steelworkers. There are only a few published studies on the respiratory health of steelworkers and these have showed that chronic bronchitis and decreased lung function values[1–5] are associated with atmospheric pollution, especially in the coke oven plant[6–9]. However, all of them lacked an appropriate assessment of dust exposure, especially the respirable fraction, leaving the question of association between actual amount and respiratory impairment still unanswered.

The purpose of this study was to investigate the relationship between respiratory health and dust exposure in steelworkers by applying standardized measurements. It was, hence, designed to determine levels of dust exposures in different job categories, to determine the prevalence of respiratory symptoms and lung function abnormalities, and to investigate their contributing factors including dust exposure and smoking history.

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Materials and Methods

Walkthrough observation and definition of exposure zones

Before the survey was undertaken, a comprehensive walkthrough observation was conducted on site by the team between March and July 1889 to obtain and study production processes and plant layout; to compile an inventory of raw materials, intermediates, by-products, and products; to obtain a list of job categories and the environmental risk factors to which steelworkers were potentially exposed; to observe the work practices and pollution controls associated with job categories, and; most importantly, to define exposure zones[10] for our sampling.

Following the site-visit observation, all the workers in the iron making and steel making factories were selected because of the high exposure of dust in this first half of the steel production process. However, considering that coke ovens are essentially chemical plants and that they principally produce coke oven emissions[11], workers in the coke ovens were excluded in order to elucidate an association between dust exposure and respiratory health. Job categories were classified by consensus subjectively according to their individual exposure characteristics as shown in Table 1. The main ingredients of dust in this iron and steel making processes contained iron ore and coal dust, iron oxide, aluminum oxide, silica dust, and metal fumes. Silica was found to be present as part of the raw material in sintering process and blast furnace, although it was usually less than 5% in the content.

Study population

All workers in the iron making factory (sinter, coal preparation, and blast furnace plants) and steel making factory (steel materials and assistant equipment, basic oxygen furnace, continuous casting, and steel slab rectifying plants) were recruited at the time of the respiratory health survey from August to September 1989. A total of 1,497 out of 1,985 workers, giving a response rate of 75.4%, completed the respiratory questionnaire and spirometry. Subjects who were unable to produce acceptable spirograms meeting the ATS criteria[15] (N=23), those who were ill e.g. chest contusion (N=12), women (N=2), and ex-smokers (N=121) were excluded from the analysis to enhance valid contrast. The remaining 1,339 workers entered the final analysis.

Exposure assessment

Before proceeding to dust exposure measurement, a pilot study was designed and undertaken. During the period between January and February 1990, the practical dust exposure measurements and their analysis were conducted. All the workers in a weekday day shift, that is about one fourth workers, were chosen for the purpose of dust sampling measurement under regular production schedule. Every effort was made to obtain full-shift samples for as close to eight hours as possible[12]. The numbers of workers and valid samples are presented in Table 1.

Personal air sampling was used to assess dust exposure in the subject's breathing zone. The sampling procedures were based on the method published by the National Institute for Occupational Safety and Health (NIOSH)[13] in the United States. The SKC® personal cyclone (Model 225-01-02) with cassette sampler was used to measure respirable dust exposure. The cassette contained a low ash polyvinyl chloride (PVC) filter paper which was completely sealed by a sealing band to prevent air leakage. When the sampling flow rate is approximately 1.9 litres per minute (LPM), a 5.0 μm aerodynamic diameter cut-point was used. The sampler connected to the SKC® constant flow sample pump (Model 224-PCXR) made up one personal sampling kit. The pump was calibrated before and after each sampling by using a Gilibrator® primary standard airflow calibrator. PVC filter paper was put in the desicator before and after sampling for 24 h, and then weighted using an electrical microbalance.

In the sampling process appropriate direction and communication was given to any steelworker who carried a sampler. Any information or observation that might be significant, e.g. process upsets, ventilation system not operating, or use of personal protection were recorded in order to let each sample represent its eight hours time weighted average as accurately as possible. Total dust (all airborne particles irrespective of size) was determined as the sum of respirable dust (particle diameter less than 5 μm) and non-respirable fraction that was collected from the cyclone holder. Respirable and total dust concentrations were calculated according to different job categories.

The survey collected 298 samples in total from February to March in 1990. The overwhelming majority of the samples were representative of an eight-hour shift. Eighteen samples were excluded from the analysis because of abnormal work routines, and three samples for technical problems, e.g. substantially decreased flow rate. As a result 277 valid samples were included in the analysis.

Measurement of respiratory health

During the period between August and September in 1989, the respiratory health survey was undertaken, including questionnaire and spirometric tests for each steelworker. Respiratory symptoms, determined by a modified version of the American Thoracic Society (ATS) respiratory questionnaire[14] translated into Chinese, was pre-tested and administered by trained interviewers. The questionnaire included questions relating to personal information, current and past occupational history in steelworks and all other jobs, subjective assessment of levels of dustiness in all jobs, present respiratory symptoms, past illness history, and smoking habits.

Table 1. Respirable and total exposure levels in 1,339 male steelworkers by different job categories

Job categories	No. of workers	No. of valid samples	Respirable dust concentration (mg·m^{-3})		Total dust concentration in (mg·m^{-3})	
			Mean	Median	Mean	Median
Total number	1,234	277				
Sinter plant						
Supervisor & engineer	20	5	0.17	0.06	2.24	1.36
Controlling room technician	20	5	0.09	0.08	0.96	0.68
Material treatment technician	24	6	0.31	0.07	5.33	1.46
Material room technician	12	3	1.05	0.53	13.59	11.70
Sintering machine technician	12	3	1.96	2.74	44.65	18.43
Dust recycling technician	12	2	5.08	5.08	30.60	30.60
Sinter cooling technician	12	3	2.28	1.04	51.23	5.85
Coal preparation plant						
Supervisor & engineer	8	2	0.16	0.16	1.45	1.45
Controlling room technician	8	2	0.02	0.02	0.20	0.20
Coal preparing technician	24	5	0.43	0.39	6.14	3.97
Blast furnace plant						
Supervisor & engineer	48	13	0.11	0.10	0.76	0.55
Controlling room technician	40	10	0.09	0.07	0.71	0.50
Material room technician	23	3	0.59	0.24	5.48	1.01
Blast furnace room technician	120	27	0.83	0.37	4.63	1.34
Assistant equipment technician	80	19	0.19	0.16	1.43	1.05
Steel material & assistant equipment plant						
Material room technician	10	2	0.36	0.36	2.48	2.48
Steel pre-treatment technician	24	5	0.34	0.44	1.31	0.80
Limestone technician	29	6	7.59	6.60	37.37	34.34
Mobile car driver	32	7	0.48	0.38	2.78	2.45
Sky car driver	97	10	0.13	0.10	1.77	0.55
Basic oxygen furnace plant						
Supervisor & engineer	28	7	0.17	0.16	1.02	0.65
Refining process technician	80	25	0.26	0.25	2.25	1.79
Waste system technician	18	4	0.21	0.19	1.48	1.42
Refining equipment technician	48	11	0.31	0.20	1.85	1.02
Continuous casting plant						
Supervisor & engineer	40	3	0.64	0.23	4.39	3.17
Casting process technician	208	52	0.48	0.18	3.72	1.38
Cutting process technician	45	9	0.32	0.11	3.71	1.19
Casting equipment technician	40	11	0.79	0.42	3.15	1.46
Steel slab rectifying plant						
Secondary cutting technician	32	7	0.16	0.16	0.69	0.79
Steel slab treatment technician	40	10	1.14	0.16	6.93	1.16

The respiratory questionnaire responses also yielded subjective indicators of dust exposure, i.e., subjective dustiness in current job and past jobs. These indicators have four levels corresponding to none, slight, moderate, and severe. Hours exposed to dust per day were also asked in the questionnaire and were divided into five levels corresponding to 0, 1–2, 3–4, 5–6, and 7–8 h. The following definitions of smoking were used: non-smokers were all workers who had ever smoked less than 20 packs of cigarettes (20 cigarettes in one pack), 300 g of tobacco in a lifetime, or less than one cigarette a day for one year; ex-smokers were those who had stopped smoking at least one month before testing; and everybody else was classified as being a current smokers. Several variables representing smoking habits were created after the exclusion of ex-smokers. First, the workers were grouped into non-smokers and current smokers using the current smoker variable (yes/no). Second, lifetime cigarette consumption was coded and analyzed as a continuous variable - cigarette equivalent (packs per day multiplied by no. of years).

Before spirometric tests the standing height and weight of each subject was measured and read off by one assistant. Lung function was then examined by two doctors using the standard spirometric test recommended by the ATS[15]. These were performed with the Microspiro® HI-298 Model spirometer for the measurement of forced vital capacity (FVC), forced expiratory volume in one second ($FEV_{1.0}$), forced expiratory volume in one second as a percentage of the forced vital capacity ($FEV_{1.0}$/FVC). The machine was calibrated before and after each day's use without any significant differences being found. Before examination each subject was given the opportunity to learn the technique while watching others blew into the spirometer. The subjects were measured sitting with nose-clips fitted, and the spirometric reading was taken best of three acceptable tracings that met the acceptability and reproducibility criteria. As the spirometer is a flow-measuring device, it was reasonable to neglect the body temperature pressure saturated (BTPS, temperature 37°C, ambient pressure, saturated with water vapor at 37°C) conversion under environmental conditions.

Definitions of respiratory symptoms

In this paper, cough frequently refers to cough usually on most days for three consecutive months or more during the year and chronic cough to previous symptom for more than two years. Phlegm frequently refers to phlegm production usually on most days for three consecutive months or more during the year and chronic phlegm to previous symptom for more than two years. Wheezing occasionally is defined as an attack of wheezing apart from colds and breathlessness as shortness of breath when hurrying on the level or walking up a slight hill. Past respiratory illnesses are defined as any history of respiratory disease including bronchitis, pneumonia, bronchiectasis, chronic bronchitis, emphysema, asthma, pleuritis, pulmonary tuberculosis, or any chest operation, confirmed by medical doctors, before entering the company and past dusty occupations as past dust exposure for more than two years before entering the company.

Statistical analysis

Following data coding, entry, checking, and linking, analysis was performed using the SAS-PC statistical package[16, 17]. The means and medians for respirable and total dust concentration in different job categories were calculated. Those that were not measured were assigned to similar ones on the basis of the site-visit observation. Due to the log-normal distribution of dust samples, medians of dust concentrations were more representative. The medians of respirable and total dust concentrations in different job categories represented respirable and total dust exposure in the current job, respectively.

Because of the lack of data concerning dust exposure in the past, a commonly used procedure was followed, in that cumulative dust exposure was defined as:

$$\textit{Cumulative dust exposure} = \sum_{\textit{All jobs}} [(\textit{Median concentration of dust exposure at job}) \times (\textit{Years at job})]$$

According to the above equation and occupational history, the cumulative respirable and total dust exposure for each steelworker could be hypothetically estimated in order to investigate the dose-response relationships with biological variables.

Logistic regression analysis was applied to identify the factors related to respiratory symptoms. The outcome variables analyzed were cough frequently, chronic cough, phlegm frequently, chronic phlegm, wheezing occasionally, and breathlessness. The exposure variables used were duration of employment, cumulative respirable and total dust exposure, average respirable and total dust exposure (i.e. cumulative exposure/duration of employment), respirable and total dust exposure in current job, and subjective dustiness and hours exposed to dust per day in current job. The confounding variables controlled were age, duration of smoking, cigarette equivalent, average smoking index (i.e. cigarette equivalent/years smoked), past dusty occupations, and past respiratory illnesses. Using the logistic model, adjusted odds ratios and confidence intervals of respiratory symptoms were calculated for any predictive variable.

Multiple linear regression analysis was applied to identify the factors associated with lung function values. For checking whether or not the effect of dust exposure was different between smokers and non-smokers, separate analyses were performed. The outcome variables analyzed were FVC, $FEV_{1.0}$, and $FEV_{1.0}$/FVC. The exposure variables used were duration of employment, cumulative respirable and total dust exposure, average respirable and total dust exposure, respirable and total dust exposure in current job, and subjective dustiness and hours exposed to dust per day in current job. The confounding variables controlled were age, age^2, height, weight/$height^2$, duration of smoking, cigarette equivalent, average smoking index, and past dusty occupations, and past respiratory illnesses. An ethnicity variable was abandoned because it did not significantly contribute to the model of lung function values. Objective dust exposure indicators and smoking index were not normally distributed and were therefore transformed logarithmically to yield log-normal distributions before the analysis commenced. A stepwise method was carried out as a means of assessing the relative priority of associations between multiple variables.

Table 2. Comparison of general information in 1,339 male steelworkers by different cumulative respirable dust exposure categories

General information	Cumulative respirable dust exposure ($mg·m^{-3}·yr$)				
	<0.50	0.50–0.99	1.00–1.99	2.00+	Total
Total number	309	265	371	394	1,339
Age (yr)[a#]					
20–29	230 (74.4)	86 (32.5)	14 (3.8)	15 (3.8)	345 (25.8)
30–39	63 (20.4)	149 (56.2)	304 (81.9)	281 (71.3)	797 (59.5)
40+	16 (5.2)	30 (11.3)	53 (14.3)	98 (24.9)	197 (14.7)
Mean age (yr)[b#]	28.8 ± 4.6	32.6 ± 5.8	35.6 ± 4.5	37.1 ± 4.9	33.9 ± 5.8
Mean height (cm)[b*]	168.6 ± 5.4	168.6 ± 5.2	168.0 ± 5.1	167.7 ± 5.5	168.2 ± 5.3
Mean BMI ($kg·m^{-2}$)[b#]	23.0 ± 2.7	23.5 ± 2.7	23.9 ± 2.5	24.4 ± 2.8	23.7 ± 2.7
Duration of employment (yr)[a#]					
1–5	246 (79.6)	94 (35.5)	10 (2.7)	13 (3.3)	363 (27.1)
6–10	39 (12.6)	104 (39.2)	159 (42.9)	67 (17.0)	369 (27.6)
11+	24 (7.8)	67 (25.3)	202 (54.4)	314 (79.7)	607 (45.3)
Mean duration of employment (yr)[b#]	4.4 ± 3.2	7.7 ± 4.1	10.9 ± 2.4	11.7 ± 2.4	9.0 ± 4.2
Duration of smoking (yr)[a#]					
Non-smoker	165 (53.4)	152 (57.4)	186 (50.1)	191 (48.5)	694 (51.8)
1–10	114 (36.9)	64 (24.2)	54 (14.6)	40 (10.2)	272 (20.3)
11+	30 (9.7)	49 (18.5)	131 (35.3)	163 (41.4)	373 (27.9)
Mean duration of smoking (yr)[b#]	3.4 ± 4.7	4.4 ± 6.2	6.6 ± 7.7	7.7 ± 8.6	5.8 ± 7.3
Cigarette equivalent (pack·yr)[a#]					
Non-smoker	165 (53.4)	152 (57.4)	186 (50.1)	191 (48.5)	694 (51.8)
1–10	130 (42.1)	87 (32.8)	104 (28.0)	86 (21.8)	407 (30.4)
11+	14 (4.5)	26 (9.8)	81 (21.8)	117 (29.7)	238 (17.8)
Mean cigarette equivalent (pack·yr)[b#]	2.1 ± 3.5	2.9 ± 5.5	5.2 ± 8.0	6.6 ± 9.0	4.4 ± 7.3
Past dusty occupations[a]	49 (15.9)	34 (12.8)	66 (17.8)	75 (19.0)	224 (16.7)
Past respiratory illnesses[a]	40 (12.9)	42 (15.8)	62 (16.7)	55 (14.0)	199 (14.9)
Subjective dustiness[a#]					
None	25 (8.1)	29 (10.9)	43 (11.6)	26 (6.6)	123 (9.2)
Slight	56 (18.1)	42 (15.8)	71 (19.1)	49 (12.4)	218 (16.3)
Moderate	85 (27.5)	96 (36.2)	122 (32.9)	113 (28.7)	416 (31.1)
Severe	143 (46.3)	98 (37.0)	135 (36.4)	206 (43.5)	582 (43.5)

Abbreviation: BMI, body mass index. [a]Values in parentheses are percent. [b]Values are mean ± standard deviation. *$p<0.05$; #$p<0.001$.

Results

The average age and duration of employment of 1,497 participants were slightly less than those of 488 non-participants with the mean ages being 34.1 and 35.2 yr, respectively; while mean duration of employment was 8.9 and 9.5 yr, respectively. However, these differences were not statistically significant by using *t*-tests. After excluding subjects with test failure or illness, women, and ex-smokers, the findings for the remaining 1,339 workers were presented here.

Dust exposure assessment

Respirable dust exposure over 5 $mg·m^{-3}$ was found for dust recycling technicians in the sinter plant and limestone technicians in the steel material and assistant equipment plant. Total dust exposure over 10 $mg·m^{-3}$ was found for material room, sintering machine, and dust recycling technicians in the sinter plant, and limestone technicians in the steel material and assistant equipment plant (Table 1). There was a highly positive correlation (r=0.96) between respirable and total dust concentration in current jobs. On the other hand, generally low correlations (r=0.07–0.14) existed between respirable/total dust concentrations and subjective dustiness/hours exposed to dust per day in current jobs.

General information

Most of subjects are ethnic Chinese except four aborigines. The mean age of the population was 33.9 (standard deviation (SD)=5.8) yr, and 85.3% of the workers were younger than 40 yr. The mean height and weight of the population were 168.2 (SD=5.3) cm and 23.7 (SD=2.7) $kg·m^{-2}$ respectively.

Table 3. Comparison of prevalence rates of respiratory symptoms and lung function values in 1,339 male steelworkers by different cumulative respirable dust exposure categories

General information	Cumulative respirable dust exposure ($mg \cdot m^{-3} \cdot yr$)				
	<0.50	0.50–0.99	1.00–1.99	2.00+	Total
Total number	309	265	371	394	1,339
Respiratory symptoms[a]					
Cough frequently*	24 (7.8)	25 (9.4)	53 (14.3)	50 (12.7)	152 (11.4)
Chronic cough**	15 (4.9)	20 (7.5)	45 (12.1)	45 (11.4)	125 (9.3)
Phlegm frequently*	36 (11.7)	30 (11.3)	72 (19.4)	58 (14.7)	196 (14.6)
Chronic phlegm**	25 (8.1)	21 (7.9)	60 (16.2)	54 (13.7)	160 (11.9)
Wheezing occasionally*	5 (1.6)	2 (0.8)	11 (3.0)	17 (4.3)	35 (2.6)
Breathlessness*	11 (3.6)	16 (6.0)	23 (6.2)	37 (9.4)	87 (6.5)
Lung function values[b]					
FVC (l)[#]	4.15 ± 0.54	4.05 ± 0.60	3.93 ± 0.54	3.87 ± 0.57	3.99 ± 0.57
$FEV_{1.0}$ (l)[#]	3.47 ± 0.46	3.38 ± 0.49	3.26 ± 0.44	3.17 ± 0.44	3.30 ± 0.47
$FEV_{1.0}$/FVC (%)**	83.7 ± 5.3	83.4 ± 5.6	83.0 ± 5.5	82.2 ± 5.6	83.0 ± 5.5

Abbreviations: FVC forced vital capacity; and $FEV_{1.0}$, forced expiratory volume in one second. [a]Values in parentheses are percent. [b]Values are mean ± standard deviation. *$p<0.05$; ** $p<0.01$; [#]$p<0.001$.

The mean duration of employment was 9.0 (SD=4.2) yr, and 54.7% of the workers had ten or fewer years of employment. About fifty-two percent were non-smokers, and 30.4% and 17.8% had cigarette consumption less than or equal to 10 and more than 10 pack·years, respectively. Before entering this company, 16.7% of the workers had been exposed to occupationally dusty environments and 14.9% had a history of respiratory diseases (Table 2).

General information grouped according to average respirable dust exposure is also shown in Table 2. The higher the cumulative respirable dust exposure, the older the workers were, the longer the duration of employment, and the more the cigarette equivalent pack·years. However, no significant differences were seen for past dusty occupations and respiratory illnesses. Also, there was no significant finding for respirable and total dust exposure in current job, and hours exposed to dust per day in current job (data not shown in the tables).

Respiratory health

Among respiratory symptoms, cough frequently, chronic cough, phlegm frequently, and chronic phlegm (11.4%, 9.3%, 14.6%, and 11.9%) had higher prevalent rates than wheezing occasionally and breathlessness (2.6% and 6.5%). The crude prevalence for all six symptoms gradually increased among the groups defined by cumulative respirable dust exposure except cough and phlegm in the highest exposure group and wheezing in the lowest group. Their mean values of FVC, $FEV_{1.0}$, and $FEV_{1.0}$/FVC were 3.99 (SD=0.57) liters, 3.30 (SD=0.47) liters, and 83.0 (SD=5.5) percent respectively. These three values gradually decreased among the groups defined by cumulative respirable dust exposure (Table 3).

Dose-response relationship

Only duration of employment remained to be associated with respiratory symptoms significantly after controlling the confounding variables shown in Table 4. The other major contributing factors to the presence of respiratory symptoms included average smoking index, past respiratory illnesses, and subjective dustiness in the current job.

Multiple regression analysis of contributing factors of lung function values in smokers and non-smokers is presented in Table 5. As expected, age, height, and body mass index variables were important determinants of lung function values. Results for smokers were different from those for non-smokers. Average respirable dust exposure was significantly negatively associated with both FVC and $FEV_{1.0}$. However, no effect was found for $FEV_{1.0}$/FVC. Smoking effect was detected on $FEV_{1.0}$ only. On the other hand, when restricted to non-smokers, the effect of average respirable dust exposure significantly decreased $FEV_{1.0}$/FVC only.

Discussion

This cross-sectional study demonstrated the significantly deteriorating effect of respirable dust exposure on FVC and $FEV_{1.0}$ in current smoking and $FEV_{1.0}$/FVC in never smoking steelworkers. Nevertheless, only duration of employment instead of respirable dust exposure gave the impact on respiratory symptoms of steelworkers.

The characteristics of this study population was special in that it was a young work force, and it might be expected that they have a shorter duration of employment and lower cigarette consumption. Under such circumstances, a cross-sectional survey is less effective than a longitudinal study.

Table 4. Factors contributing to the presence of respiratory symptoms

Respiratory symptoms	Crude OR (95% CI)	Adjusted OR (95% CI)
Cough frequently		
Age (yr)	1.00 (0.97, 1.03)	0.94 (0.89, 1.00)*
Duration of employment (yr)	1.04 (1.00, 1.09)	1.12 (1.03, 1.21)**
Cumulative respirable dust exposure (mg·m^{-3}·yr)	1.00 (0.96, 1.05)	NS
Average respirable dust exposure (mg·m^{-3})	1.04 (0.71, 1.53)	NS
Duration of smoking (yr)	1.05 (1.03, 1.07)#	NS
Cumulative cigarette equivalent (pack·yr)	1.06 (0.14, 1.08)#	NS
Average smoking index (packs)	3.44 (2.48, 4.78)#	3.24 (2.32, 4.53)#
Past dusty occupations (yes)	1.09 (0.70, 1.69)	NS
Past respiratory illnesses (yes)	1.55 (1.01, 2.38)*	1.63 (1.04, 2.54)*
Subjective dustiness (grades)	1.46 (1.19, 1.78)#	1.42 (1.15, 1.75)#
Chronic cough		
Age (yr)	1.02 (0.99, 1.05)	NS
Duration of employment (yr)	1.07 (1.02, 1.12)**	1.08 (1.02, 1.13)**
Cumulative respirable dust exposure (mg·m^{-3}·yr)	1.01 (0.97, 1.06)	NS
Average respirable dust exposure (mg·m^{-3})	1.01 (0.76, 1.62)	NS
Duration of smoking (yr)	1.06 (1.03, 1.08)#	NS
Cumulative cigarette equivalent (pack·yr)	1.07 (1.05, 1.09)#	NS
Average smoking index (packs)	3.63 (2.56, 5.16)#	3.38 (2.37, 4.83)#
Past dusty occupations (yes)	1.01 (0.62, 1.65)	NS
Past respiratory illnesses (yes)	1.86 (1.19, 2.90)**	2.00 (1.25, 3.18)**
Subjective dustiness (grades)	1.50 (1.20, 1.87)#	1.50 (1.20, 1.90)#
Phlegm frequently		
Age (yr)	1.00 (0.97, 1.03)	0.93 (0.88, 0.98)**
Duration of employment (yr)	1.04 (1.01, 1.09)*	1.14 (1.06, 1.23)#
Cumulative respirable dust exposure (mg·m^{-3}·yr)	1.01 (0.98, 1.05)	NS
Average respirable dust exposure (mg·m^{-3})	1.18 (0.87, 1.59)	NS
Duration of smoking (yr)	1.05 (1.03, 1.07)#	NS
Cumulative cigarette equivalent (pack·yr)	1.06 (1.04, 1.08)#	NS
Average smoking index (packs)	2.72 (2.01, 3.67)#	2.57 (1.89, 3.49)#
Past dusty occupations (yes)	1.05 (0.71, 1.57)	NS
Past respiratory illnesses (yes)	1.59 (1.08, 2.33)*	1.64 (1.10, 2.45)*
Subjective dustiness (grades)	1.37 (1.15, 1.63)#	1.35 (1.13, 1.61)**
Chronic phlegm		
Age (yr)	1.01 (0.99, 1.04)	0.94 (0.89, 0.99)*
Duration of employment (yr)	1.06 (1.02, 1.11)**	1.14 (1.06, 1.24)#
Cumulative respirable dust exposure (mg·m^{-3}·yr)	1.02 (0.99, 1.06)	NS
Average respirable dust exposure (mg·m^{-3})	1.27 (0.94, 1.71)	NS
Duration of smoking (yr)	1.06 (1.03, 1.08)#	NS
Cumulative cigarette equivalent (pack·yr)	1.07 (1.05, 1.09)#	NS
Average smoking index (packs)	3.01 (2.18, 4.16)#	2.80 (2.02, 3.89)#
Past dusty occupations (yes)	0.96 (0.62, 1.50)	NS
Past respiratory illnesses (yes)	1.52 (1.00, 2.31)	1.58 (1.02, 2.45)*
Subjective dustiness (grades)	1.48 (1.21, 1.79)#	1.47 (1.20, 1.80)#
Wheezing occasionally		
Age (yr)	1.03 (0.97, 1.09)	NS
Duration of employment (yr)	1.11 (1.01, 1.22)*	1.10 (1.00, 1.22)*
Cumulative respirable dust exposure (mg·m^{-3}·yr)	1.01 (0.94, 1.09)	NS
Average respirable dust exposure (mg·m^{-3})	0.86 (0.30, 2.44)	NS
Duration of smoking (yr)	1.05 (1.01, 1.09)*	NS
Cumulative cigarette equivalent (pack·yr)	1.05 (1.01, 1.08)**	NS
Average smoking index (packs)	2.23 (1.21, 4.12)*	2.15 (1.16, 3.98)*
Past dusty occupations (yes)	1.03 (0.42, 2.51)	NS
Past respiratory illnesses (yes)	1.73 (0.77, 3.86)	NS
Subjective dustiness (grades)	1.13 (0.79, 1.63)	NS
Breathlessness		
Age (yr)	1.03 (0.99, 1.07)	NS
Duration of employment (yr)	1.05 (1.00, 1.11)	1.06 (1.00, 1.13)*
Cumulative respirable dust exposure (mg·m^{-3}·yr)	1.04 (1.01, 1.08)*	NS
Average respirable dust exposure (mg·m^{-3})	1.29 (0.93, 1.85)	NS
Duration of smoking (yr)	1.03 (1.00, 1.06)	NS
Cumulative cigarette equivalent (pack·yr)	1.04 (1.01, 1.06)**	NS
Average smoking index (packs)	1.94 (1.27, 2.94)**	1.78 (1.16, 2.72)**
Past dusty occupations (yes)	1.04 (0.59, 1.85)	NS
Past respiratory illnesses (yes)	2.06 (1.24, 3.42)**	2.14 (1.28, 3.59)**
Subjective dustiness (grades)	1.48 (1.14, 1.92)**	1.52 (1.16, 1.98)**

Abbreviations: OR, odds ratio; and NS, not significant. *, $p<0.05$; **, $p<0.01$; #, $p<0.001$.

Table 5. Predictors of lung function values in simple and multiple linear regression models

Predictors	Smokers		Non-smokers	
	Simple	Multiple	Simple	Multiple
	FVC (l)			
Constant	–	–4.221[#]	–	–3.739[#]
Age (yr)	–0.036[#]	–0.022[#]	–0.028[#]	–0.017[#]
Height (cm)	0.063[#]	0.056[#]	0.059[#]	0.054[#]
BMI ($kg \cdot m^{-2}$)	–0.046[#]	–0.021**	–0.047[#]	–0.030[#]
Duration of employment (yr)	–0.042[#]	NS	–0.032[#]	NS
Cumulative respirable dust exposure ($mg \cdot m^{-3} \cdot yr$)[a]	–0.269[#]	NS	–0.143**	NS
Average respirable dust exposure ($mg \cdot m^{-3}$)[a]	–0.079	–0.097*	0.048	NS
Duration of smoking (yr)	–0.025[#]	NS	–	–
Cigarette equivalent (pack·yr)[a]	–0.236[#]	NS	–	–
Average smoking index (packs)[a]	–0.202**	NS	–	–
Past dusty occupations (yes)	–0.028	NS	–0.074	NS
Past respiratory illnesses (yes)	0.016	NS	–0.023	NS
Subjective dustiness (grades)	0.005	NS	0.015	NS
R	–	0.64	–	0.59
	$FEV_{1.0}$ (l)			
Constant	–	–2.037[#]	–	–1.554*
Age (yr)	–0.035[#]	–0.025[#]	–0.027[#]	–0.019[#]
Height (cm)	0.046[#]	0.039[#]	0.041[#]	0.036[#]
BMI ($kg \cdot m^{-2}$)	–0.039[#]	–0.017*	–0.040[#]	–0.025[#]
Duration of employment (yr)	–0.042[#]	NS	–0.032[#]	NS
Cumulative respirable dust exposure ($mg \cdot m^{-3} \cdot yr$)[a]	–0.267[#]	NS	–0.182[#]	NS
Average respirable dust exposure ($mg \cdot m^{-3}$)[a]	–0.085	–0.091*	–0.011	NS
Duration of smoking (yr)	–0.027[#]	NS	–	–
Cigarette equivalent (pack·yr)[a]	–0.254[#]	NS	–	–
Average smoking index (packs)[a]	–0.208**	–0.099*	–	–
Past dusty occupations (yes)	–0.030	NS	–0.083	NS
Past respiratory illnesses (yes)	–0.066	NS	0.015	NS
Subjective dustiness (grades)	–0.001	NS	0.012	NS
R	–	0.63	–	0.55
	$FEV_{1.0}$/FVC (%)			
Constant	–	116.93[#]	–	117.77[#]
Age (yr)	–0.12**	–0.16[#]	–0.08*	–0.11*
Height (cm)	–0.13**	–0.17[#]	–0.17[#]	–0.19[#]
BMI ($kg \cdot m^{-2}$)	–0.02	NS	–0.02	NS
Duration of employment (yr)	–0.15**	NS	–0.13*	NS
Cumulative respirable dust exposure ($mg \cdot m^{-3} \cdot yr$)[a]	–0.98*	NS	–1.52**	NS
Average respirable dust exposure ($mg \cdot m^{-3}$)[a]	–0.42	NS	–1.32*	–1.34*
Duration of smoking (yr)	–0.14**	NS	–	–
Cigarette equivalent (pack·yr)[a]	–1.34**	NS	–	–
Average smoking index (packs)[a]	–0.93**	NS	–	–
Past dusty occupations (yes)	–0.17	NS	–0.52	NS
Past respiratory illnesses (yes)	–0.68	NS	–0.31	NS
Subjective dustiness (grades)	–0.09	NS	–0.01	NS
R	–	0.21	–	0.21

Abbreviations: BMI, body mass index, FVC forced vital capacity; $FEV_{1.0}$, forced expiratory volume in one second; NS, not significant; and R, multiple correlation coefficient. [a]Logarithmic transformation before analysis. *, $p<0.05$; **, $p<0.01$; [#], $p<0.001$.

The study population did not include any terminated employment which is one component of a healthy worker effect[18]. The non-participants were older than the participants although no significant difference existed. There could thus be some under-estimation of the effect of interest due to selection bias, and a cross-sectional survey would tend to underestimate effects of interest.

Problems with reliable workplace information due to misinformation, sudden changes in production process, breakdown of technical equipment, constraints on access to workers, and other problems that were difficult to anticipate and rule out in advance could give rise to inaccurate dust measurements. Dust exposure in some job categories such as dust cycling technicians may not be determined accurately due to only a few samples collected. Moreover, because of the lack of data concerning dust exposure in the past, only the cumulative dust exposure according to occupational history can be estimated. Subsequently, misclassification from dust exposure grouping may have resulted in an underestimation of the mean differences between the groups, and therefore in an underestimation of the dose-response relationships for respiratory health outcomes. There is also an anticipated effect of excluding 23 workers who were unable to meet the requirements of the criteria established by the ATS[15] for spirometry, which may contribute potential biases towards the null in this study[19–21].

A general dust hazard is considered to exist in jobs whose respirable dust concentration exceeded 5 $mg \cdot m^{-3}$ or total dust concentration exceeds 10 $mg \cdot m^{-3}$ in few job categories[22] (Table 1). We visited those jobs' places again to verify the zoning of high dust exposure. Although these cannot be excluded subjectively, it may also obscure a causal association due to exposure misclassification, if any.

Because of numerous ingredients and relatively low silica content in respirable dust in the integrated steelworks, it is reasonable to assess the association between airborne exposure and respiratory health using a general rather than specific pollutant effect. No increased prevalence of respiratory symptoms among the objective dust indicators, either respirable or total, was seen in this study other than duration of employment and subjective dustiness. Possible explanations for the lack of an effect is the lower prevalence rate compared with other studies[1, 2] and the retrospective assessment and possible random misclassification of the exposure group due to the lack of data of dust exposure in the past. These factors would tend to obscure the real effect.

The multiple regression analysis of the lung function values showed a clear dose-response effect for $FEV_{1.0}$/FVC with the most precise dust indicator, namely, average respirable dust exposure in the non-smokers. The lower $FEV_{1.0}$/FVC in non-smokers is probably because it was achieved at lower expiratory volume in the first second compared with its vital capacity. On the other hand, there was a different effect in the smokers in that increasing average respirable dust exposure was associated with reducing $FEV_{1.0}$ as well as FVC. Consequently, the effect on $FEV_{1.0}$/FVC cannot be seen in the model. However, Pham *et al.* detected a significant deterioration of $FEV_{1.0}$ and $FEV_{1.0}$%FVC in steelworkers compared with a reference group of unexposed workers in a five-year longitudinal study[2]. Wang *et al.* found significant loss of $FEV_{1.0}$, FVC, and $FEV_{1.0}$%FVC at the cross-sectional baseline data, whereas the association between dust exposure and longitudinal decline of lung function was weak[4]. Nemery *et al.* also showed that the more pronounced decrease in $FEV_{1.0}$ and $FEV_{1.0}$%FVC found over the night shift of strandcasting workers in an over 21 d shiftwork[3]. It is not totally clear about the cause of a negative dust effect on FVC in smokers. Silica contained in respirable dust could be a potential factor though no silicosis case was found from annual chest X-ray examinations in this company.

Both duration of employment and subjective dustiness entered into the final models for respiratory symptoms, while only respirable dust exposure did for lung function. Dust sampling would differentiate on an objective basis, while the experience of workers would limit their ability to classify exposure correctly. Thus, dust exposure measurement especially the respirable fraction needs be assessed instead of subjective indicators by questionnaire to detect a respiratory ill effect. Except particle size and concentration, the composition of dust exposure also contributes primarily to the effect. This study did not analyze the component of dust. It should be careful to assess the adequacy of applying the threshold limit value for nuisance particulate.

Becklake has reviewed the literature on chronic non-specific lung disease associated with occupational exposure[23]. This disease includes a cluster of symptoms related to chronic bronchitis and a reduction in lung function associated with obstructive lung disease. Previously there was much debate as to whether dusty work environments could be an etiologic factor as Morgan found that industrial bronchitis might not be associated with decreased lung function values[24]. However, recent studies provide strong evidence for the independent role of dust in the causation of this disease[25–32].

Respiratory ill health is a result of multiple etiologic factors and this gives rise to difficulty when disentangling the influence of the various factors on the disease. This study has been able to control the smoking variable, a known contributor, and it demonstrated statistically significant associations between the outcome variables of interest and respirable dust exposure. In general, smoking played more of a role than dust exposure in the determination of respiratory symptoms. Smoking was also associated with the diminution of the lung function values. It provided further corroboration for a deleterious dust related effect on the respiratory system for steelworkers.

In summary, we concluded that results from the analysis of symptoms and lung function changes in relation to respirable dust exposure add further weight to the body of evidence connecting industrial dust exposure to subjective and objective respiratory ill effects other than pneumoconiosis. Follow-up studies using standardized methods are strongly suggested for further evidence of causality.

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